LASER PROJECTION LINKS COMPOSITE DESIGN TO MANUAL FABRICATION

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SUMMARY : This paper baselines the current state of methods and applications that employ computer data to direct composite manufacturing processes. Industry needs, emerging solutions, and potential research to advance these technologies are addressed. It contrasts today's processes to laser based virtual operator assistants and encourages scientific exploration and developments to maximize the utilization computer model data for minimum product costs. Computer graphics for design and analysis is creating extensive electronic data for product definition. The improved visualization, simulation and accuracy of 3-D images is enhancing quality and reducing design costs. Laser Projection is emerging as a viable method to clearly and accurately display computer model data for worker instructions.

Applications are expanding. Today laser images direct manual cutting, pickup, and placement of composite laminates. Tomorrow they will provide complete identification, validation, inspection, and assembly guidance. This technology may truly represent the missing link between human operators and computer data.

KEYWORDS: Laser, Low-cost, Manufacturing, 3-D, Industry Needs, Layup, Inspection, Cutting, Kits, Identification

INTRODUCTION

The same model data that is used to define products can often be reused with little or no modification as direct input to numerically controlled factory equipment for milling, drilling, painting, or composite tape and tow placement. Unfortunately only a small percentage of the total manufacturing processes, normally those which are performed by numerically controlled machines and equipment, can benefit from the multiple use of data that was produced for design or analysis. The rapid expansion in the quantity of new products being designed by computer aided design systems coupled with the limited direct links to manufacturing processes is leading to an increase in the use of "human interfaces" between computer databases and manufacturing processes. This means that increasingly large amounts of structured data is being created to optimize the design process and left for human interpretation and translation into manufacturing instructions, specifications, and controls.

Even though, very complete and often complex computer models exists for a product the output of the CAD system is all too often a paper printout. These documents generally come in the form of drawings, work instructions, specifications, etc. Some are electronically transferred directly from the design model but most are recreated by the engineers and analyst after viewing and studying the computer model. They convert the images and text that they see into written or graphic requirements and instructions for factory personnel to subsequently view again and interpret as they are applied to the product. Tooling and Planning Engineers use similar methods to concept, define, and design tools to control processes or product configuration. The time spent viewing, analyzing, and regenerating this data for instruction is essentially non-value-added work. Clearly there must be a better way for this data to be converted into information and methods that can be used to improve manufacturing cost and quality of products without these labor intensive efforts.

Locating computer terminals in the factory work area is a step in the right direction, but this solution still falls short of the ultimate goal of a direct link between the source of the data and the user. Often monitors can not be located at the point of use thus further contributing to non-value-added work by forcing the user to leave the work area or at least break the concentration and rhythm that is present during highly productive work just to read the next set of instructions.

"Immersive technologies" may hold the answer to accurately and rapidly conveying 3-D computer instructions directly to a person at work in a factory environment. Imagine a work cell where 3-D data could be extracted from the product design and process simulation model and then be projected to represent precise full-size images in a manner that would guide and direct the worker through every task. This same system would sense all changes to the work cell environment. No, this is not impossible as a matter-of-fact elementary factory level immersible work cells are in active production for the manual layup of composites today.

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The development and acquisition of robotics and automated or numerically controlled machinery for composites can be very costly. In addition to the high procurement costs many past development attempts have been only marginally successful. For this reason even though the manual lay-up process for composites is labor intensive and error prone it remains as today's dominate fabrication method. As composite usage increases the high cost battle of technology versus labor continues to escalate.

The defense industry is still working to overcome the technical limitations of automated mechanical solutions. Meanwhile, weapon manufacturers continue to increase the use of composite materials to meet performance requirements. They are constantly plagued by the high production costs of these new materials. Declining production rates and order quantities further compound the composite automation problem. Smaller contract quantities and slower rates increase the investment risks of large scale fixed assets and automation developments. These same factors are driving industry to adopt Lean Production [1] principals to combat increasing competition for market share. Lean Production eliminates non-value-added work and equipment. Throughput speeds are increased and costs are reduced. Examples of non-value added work for composites include extensive analysis, setup, inspection, support and discrete part tooling.

Laser projection systems[2] are being developed as near term low risk solutions to eliminate much of this non-value-added work while maintaining a man-in-the-loop to overcome the physical limitations of robotic equipment. Robots have been used more successfully to assist rather than replace technicians. This had led to the development of systems to reinforce the operator with virtual operator assistants that greatly speed up manual processes. For example, Laser projection systems (Fig.1) are being used to illuminate the work area with precise full size images of composite work-pieces at sequential in-process states of completion.

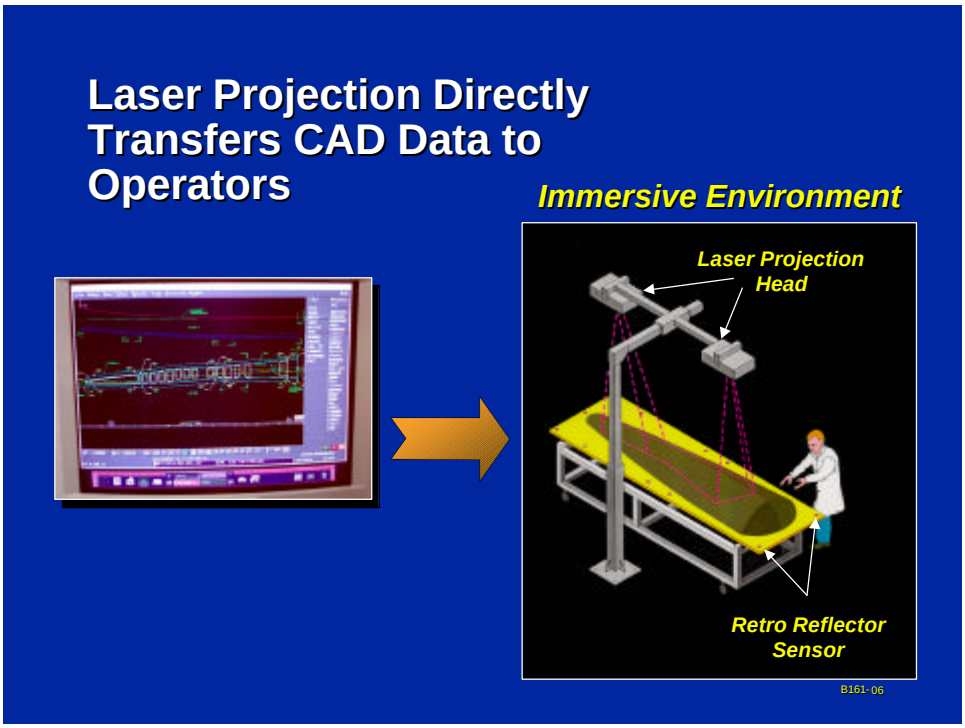

Figure 1: Laser Projector

The profile, orientation and identity of each composite ply is projected onto flat or compound contoured tools and subsequently onto the previously laid composite plies. Some of the systems are self-aligning to sensors located on the tools thus avoiding non-value-added setup. The lay-up technicians use hand held infrared remote control units to move rapidly through the 3-D CATIA database. The laser projector becomes the mechanism to convert the work area into a combination physical and virtual workspace. The operator experiences instantaneous life size work instructions. Precise profiles of each ply are projected onto the tool along with the identification number and fiber direction. This provides a visual verification and match of the precut ply profile and fiber orientation to the design database. The speed and accuracy of these full size visual placement instructions eliminate the "think time" and errors normally associated with the manual process. Once a ply is in place or an operation is complete the operator calls for laser verification of the ply placement. The laser projects acceptance or rejection of the ply position and the operator uses the remote control unit to request subsequent instructions to continue. Immediately the next image is displayed. The time and costs related to overlay templates and tedious measurements are eliminated. Lay-up speed is greatly increased and the associated throughput time is proportionately decreased. The laser projector is truly a flexible "Lean Production" machine. This eliminates tools, setup, and drawing interpretation errors while speeding up throughput and improving part quality. The early success of systems like this has led to the identification of several follow-on applications for near term implementation.

Compared to the traditional method for composite layup this process eliminates essentially all of the non-value-added-work. (Fig.2) The time previously required for a layup technician to analyze the drawing and specifications, read and understand the work instructions, position tooling templates, find an inspector, and wait for him to measure the ply placement is eliminated. (Fig.3)

Figure 2: Elimination of Non- Value- Added- Work and Tools

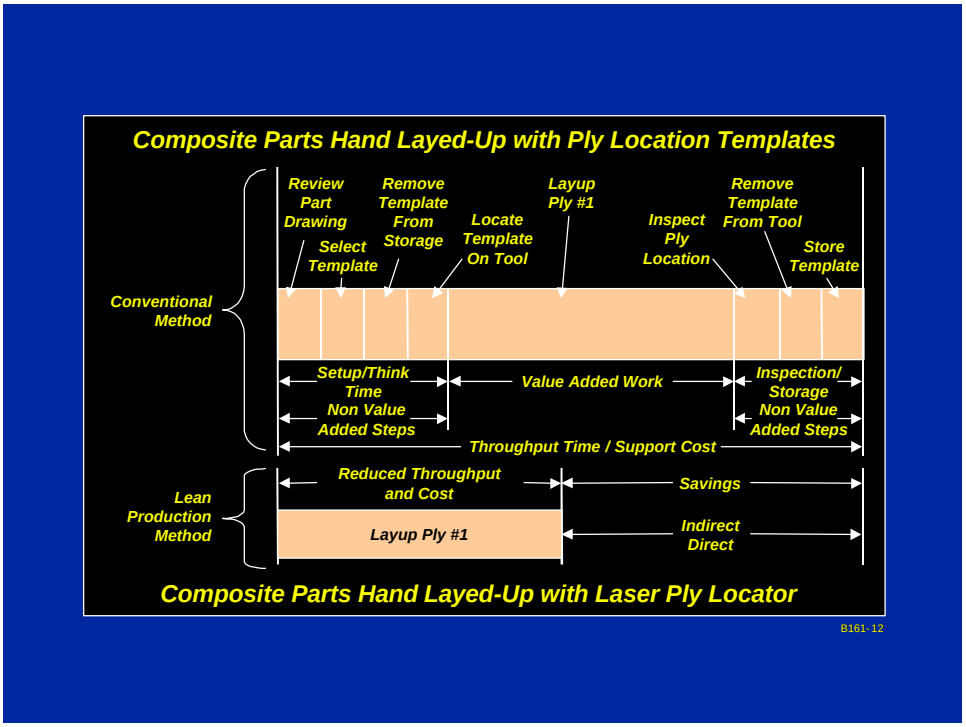

Figure 3: Savings from Laser System

EMERGING APPLICATIONS:

Composite Ply Cutting-

A new laser projection system is being developed to streamline the process for kitting and stacking cut plies in the proper sequence for layup. A projector similar to the one used in the lay-up cell is mounted in the ceiling above the automated flat bed composite cutter. The computer product model data is converted to flat patterns, sequenced, nested, and downloaded to the cutter controller. Approximately 40 feet of composite material 8 feet wide is pulled from the roll and vacuumed securely to the cutter bed. An ultrasonic knife rapidly cuts the material into dozens of discrete shapes. The operator quickly removes all of the cut pieces from the bed without regard to sequence. This allows the cutting of the next nest to begin. The process of resorting, sequencing, and stacking into orderly lay-up kits is then performed concurrent with the cutting.

Once the laser pointer system is operational this task will be eliminated. The material will be cut as before. Instead of random pickup of the cut plies the overhead laser will guide the operator by painting lines around the ply to be selected from the nest in the proper kit stack sequence. As the ply is removed from the cut nest the laser senses the operators hand movement and immediately draws a line to and around the periphery of the next ply in the proper pick and stack sequence. This point and pick process is repeated in rapid succession. Following the removal of all plies the cutting of the next nest can begin. This method will reduce the labor of sorting, the errors that result from improper sequencing, and provide orderly kits directly from the cutter that are ready to be moved as a group to the lay up cell.

Laser projection can greatly speedup cutting, kitting, lay-up and at the same time enhance the quality of composite components. The associated throughput time is proportionately decreased. It eliminates tools, setup, and drawing interpretation errors while speeding up production, improve product quality and combat the high costs of composites production.

The potential for wide use of this concept in manufacturing warrants additional expansion of laser projection and new development of associated technologies to enable the creation of immersive environments for factory level functions. The early success of these pilots has led to the recognition and identification of several follow-on applications that are maturing for near term implementation.

Painting-
Laser projection is in the trial evaluation and demonstration phase for guiding workers to precisely locate precut decals onto the outside of aircraft. A related but potentially much higher volume use of this technology involves pre-cutting large quantities of colored adhesive film materials to completely cover the outside of an aircraft thus eliminating the environmental hazards associated with application and removal of paint.

FUTURE APPLICATIONS:

Assembly Kit Buildup-
Projection technology is also envisioned as a means to guide an operator to select, sequence and place the components into an assembly kit. Take this development one step further and use the laser to reduce or even eliminate the need for assembly fixtures by providing precise projections for component location. The projection could even include highlighting of the current component of interest, sequentially guiding the installation, methods and even instructions for operation and testing of the functionality.

Wire Harness Fabrication-
Today most wire harnesses are developed and assembled on wire form boards. The boards support the wire bundle as the individual wires are added. The termination points are normally identified on the board and the wire ends are generally clamped or otherwise secured to the board. Locating the proper wire terminals for a specific wire can be labor-intensive. All too often the sequence of routing and even the path is left up to the wire routing technician. This can result in wires of varying lengths and more non-value-added work for the technician. A projection system could eliminate the searching for wires and terminals, standardize the routing sequence, rapidly point to the starting and ending terminals and illuminate the best route for the wire.

Fastener Installation-

One would imagine that the process for an aircraft mechanic to manually install a single fastener in an array of other fasteners would be straight forward and relatively simple but the variety of fasteners, processes and tools required can be mind-boggling. A typical scenario would begin with establishing the location, type of fastener, nut, washer, spacer etc. The operator must then determine the size and type of drill bit, the drill motor type and size, type and size of reamer, type and size of countersink, feed, speed, or other special operation instructions. Finally the hole is drilled and possibly reamed or maybe step-drilled. The hole must now be de-burred. This often requires parts to be separated de-burred and then reassembled. If required sealant must be added to the hole, the appropriate wrench, socket and/net runner selected and the fastener is finally installed. Imagine the opportunity for errors, the amount of non-value-added work, and the almost unbelievable "think time" associated with searching for the correct components, processes, or for determining the proper sequence as this scene it repeated thousands of times for a typical aircraft assembly. Virtual immersive factory workstations could eliminate most and in some cases all of the non-value-added work associated with this job.

Inspection-

The use of ultrasonics and real-time x-ray for non-destructive inspection are providing the ability to peer past the surface of both metal and composite structures. Operators can even establish 3-D definitions of internal anomalies or areas of interest. Unfortunately, the output from most of these systems is also limited to printouts, photos or CRT images. Often this form of output can provide extremely clear images of the anomalies but they can require extensive efforts to accurately relate the area of interest directly to the component that was evaluated. In addition to being tedious this process is also prone to positioning and location errors when the areas of interest are superimposed and marked on the component being inspected. This is another potential application where Projection Technology could provide immediate and accurate feedback to enable the scanning technician to precisely an instantaneously locate the area of interest or anomaly on the surface of the components being imaged thus eliminating errors, reducing costs and speeding the process for repairs.

As we look to the future perhaps it is best to categorize, combine, and generalize applications as a means to identify and address the generic technological needs to enable virtual factory floor work instructions to become a reality. Perhaps one of the best ways to illustrate and understand the needs would be to begin by imagining a worker performing essentially any task surrounded by a realistic, full-size, 3-D in-process virtual image. Further reality is added to this scene by the inclusion of multimedia text and sound to provide clear and concise visible and audible work instructions. These highly sensory instructions are delivered directly to the point of use without the worker leaving the area or even looking away from the job at hand. They are interactive. As the worker completes a task or a physical component replaces a virtual component the virtual image is automatically updated to lead the worker through the next task. The active virtual components are highlighted to depict the exact positioning and manipulation required by the worker. This life size dynamic interactive simulation would continue until all tasks are complete. Even though this concept seems futuristic a large portion of the enabling technologies are already at various levels of development or implementation in other applications or less hostile environments.

TECHNOLOGY DEVELOPMENT NEEDS:

Many of the technologies required to implement a virtual factory workplace are available. However additional research and development is needed to exploit this process to its fullest potential. One of the biggest technological challenges is how to satisfy the need for high-resolution display of text and fine lines in natural day or artificial light. The current use of lasers to rapidly project single lines into the work area is highly analogous to the use of vector graphics 15 years ago. At a time when vector technology seemed to open the door for 3-D design and simulation the size the models and the physical limits of the vector displays appeared to create a barrier to the imagined growth for this exciting new tool for engineering and design. Fortunately raster graphics technology came to the rescue, eliminated the flicker problems, and made realistic shaded 3-D solid images possible.

The stage is set and the need is emerging for similar advancements to make the 3-D workspace a reality. Likewise the change from a limited quantity of color vectors to multicolor life size images is needed to not only add realism and clarity but also to allow instruction projections to appear as computer generated solid models overlaid on physical components in the virtual factory workplace.

In order to be an effective virtual tool the worker must be able to move freely about the workspace without ancillary equipment, umbilical wires or other constraining or limiting equipment. The visibility must remain constant as the user moves through the workspace. This means that multiple concurrently synchronized projectors or lens must be placed around the space to eliminate shadowing of the virtual model.

In order to achieve a truly interactive environment between a user and the model data database sensors and software must be developed to constantly monitor changes in the workspace and correlate the environment to the database. In addition to methods for communicating the environment to the system sound and voice are needed for the virtual operator assistant to provide directions to the human operator and from the human operator to the virtual assistant. This too must be accomplished in a manor that does not constrain the user but that can overcome the interference and harsh environment of a factory work area.

The potential of this technology can be far reaching. The creation of a true virtual factory workspace may seem futuristic but both the foundation for the technologies and the need exists. Laser projection technology even though limited in its resolution has demonstrated a near term practical application as well as a need for advancement of the concept of humans working interactively in a hybrid of physical and immersive computer environments.

Holograms are becoming commonplace for entertainment and toys. Small displays are extremely realistic. They can even be created with special shaped mirrors that project lifelike images using only the light gathered from the room. These 3-D solid appearing images seam to float in space above or in front of the mirrors [3].

The size and dynamics of 3-D holograms is increasing. The automotive industry took a major step in January 1999 by producing a large hologram for promotional advertisement at the North American International Automotive show in Detroit[4]. The display featured a realistic 1/2size engineering concept of an automobile that hasn't been built. Full-size holograms are near and with proper direction of Research, Development and Implementation of laser projection and the enabling technologies outlined in this paper full-size Virtual Factory Workspaces linked directly to the product design should not be far behind!

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